Air Force Research Laboratory
Space Vehicles Directorate

Overview – Space Applications and Opportunities

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Challenges of Modern Space Systems

- **Current systems are large and complex**
  - **Expensive to design, build and launch**
  - **Long development times, technically obsolete at launch**
  - **Launch Costs are Prohibitive**
  - **Static designs with no adaptability to evolving world situations and threats**

New paradigms required to change the order of business for Air Force

- Basic rethinking of space system architectures
- Simultaneous attack on performance *and* cost

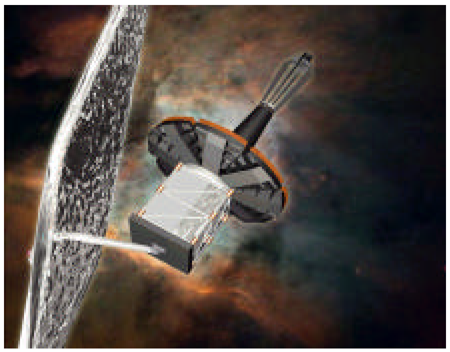
Space Applications that Need Tech Insertion

- **Large Optical Systems**
  - Surveillance and Directed Energy
- **High Power Spacecraft**
  - Large PV Arrays
- **Launch Environment Mitigation**
  - Vibration, Acoustics, and Shock
- **Docking for On-Orbit Servicing**
  - Smart Docking Mechanisms vs. Smart Servicing S/C

Large Space Optics Technology Needs

Next Generation Space Telescope

Cryogenic
Inflatable Sun Shield



Space-based Laser

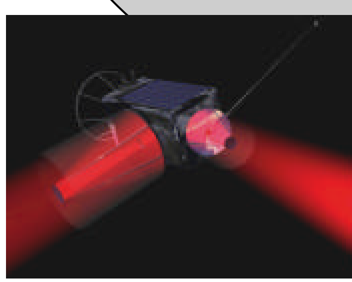
Thermal Control
ATP/FC
Laser Disturbance

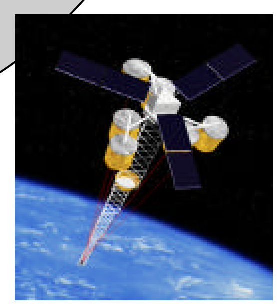
Common

Adaptive Optics
Lightweight Mirrors
Lightweight Structures
Mechanisms
Precision Structures
Micro-dynamics
Wavefront Sensors
Integrated Controls
End-to-End Integrated Modeling

Relay Mirror

Gimbaled Telescopes
Laser Beacon on
Articulated Boom
Beam Cleanup
Momentum Control



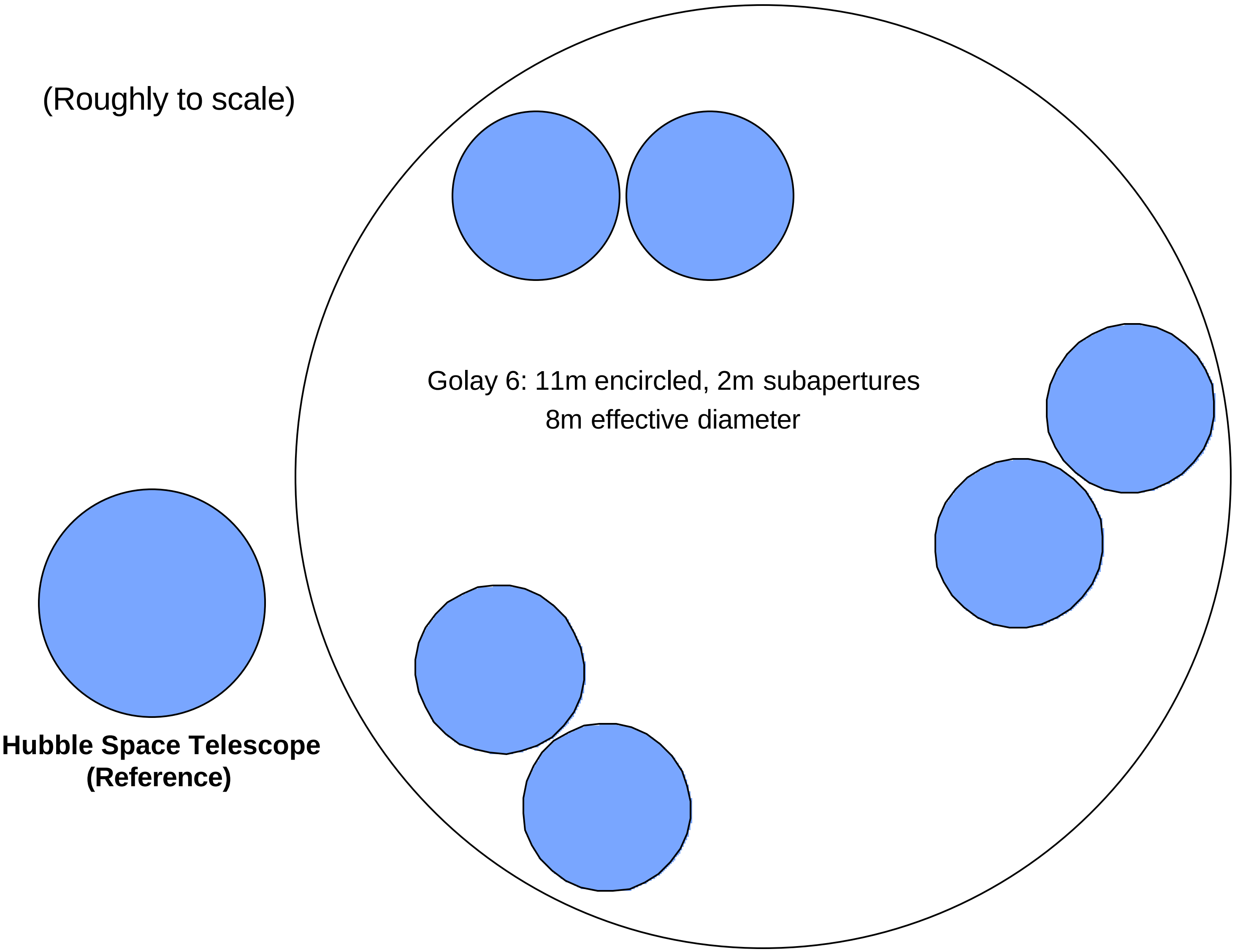


Tactical Imaging

Agile Targeting
Geolocation
Inertial Reference

Aperture Comparison Summary

(Roughly to scale)

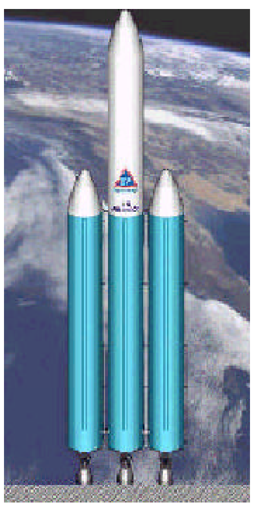


Launch Vehicle Constraints on Maximum Satellite Size and Weight

Space Shuttle

Titan IV

EELV

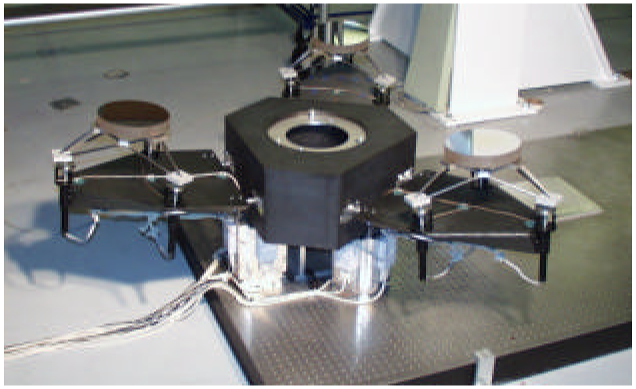


- All available choices currently constrained by ~5 m diameter
- Available weight depends on specific launch vehicle and orbit

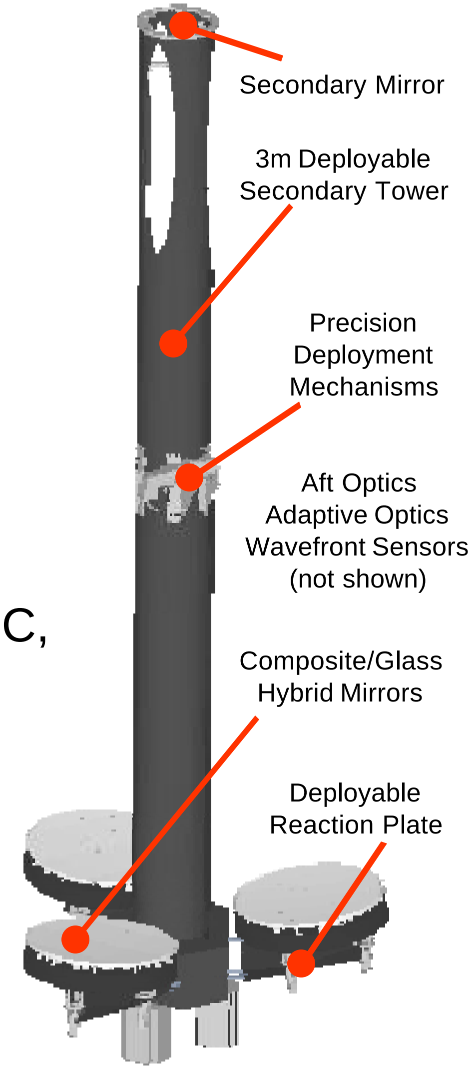
Lightweight Space Optics Technical Needs

- Lightweight Mirrors
  - Scalable approaches to large-aperture lightweight mirror structures
- Lightweight Precision Structures
  - High-stiffness structures providing optical precision dimensional stability
- Deployment Mechanisms for Optical Systems
  - Precision deployment mechanism concepts for space optics systems.
- Integrated Opto-Mechanical Control Systems
  - Innovative, traceable approaches to high-performance control systems
- End-to-End Integrated Modeling
  - Tools & software to provide system-level performance and trades

AFRL's Deployable Optical Telescope (DOT)



- Objectives:
  - phasing & maintenance of segmented primary mirror
  - deployment, capture, and maintenance of secondary mirror
  - Demonstration of traceable control algorithms,WFS/WFC, mechanisms, and advanced actuators
- Testbed Description
  - f/20 sparse phased-aperture telescope
  - 3 sub-apertures, fill factor = 29%
  - 1.7 m encircled aperture dia. (1.5 m eff)
  - 0.6 m sub-aperture diameter



Technical Metrics/Goals

	Goal	Current Values
Sub-Aperture Phasing		
Accuracy (segment-to-segment OPD)	0	< 1 nm (1/600 wave)
Complexity, Autonomy, Traceability, Cost	Min/Max, Subjective	
Deployment mechanisms		
Accuracy	< 10 microns	*
Repeatability	1 micron (2 ♦)	*
Stability	Incidence frequency, magnitude, hysteresis	*
Deployed Stiffness	1 M lb/in (SBL)	*
Precision Structures		
Dimensional Stability	Expansion coefficients	?
Stiffness (1st mode)	>40 Hz	25-30 Hz
Lightweight Mirror Structures		
Areal Density	< 10 kg/m^2	< 12 kg/m^2
Surface accuracy	< 1/30 wave rms	> 1 wave rms
Radius of curvature matching	⌖40 microns	*

Role for Smart Materials

- **Actuators**
  - Huge Dynamic Range (nm to cm)
  - Compact and Light (including electronics!!!)
  - Space Survivable

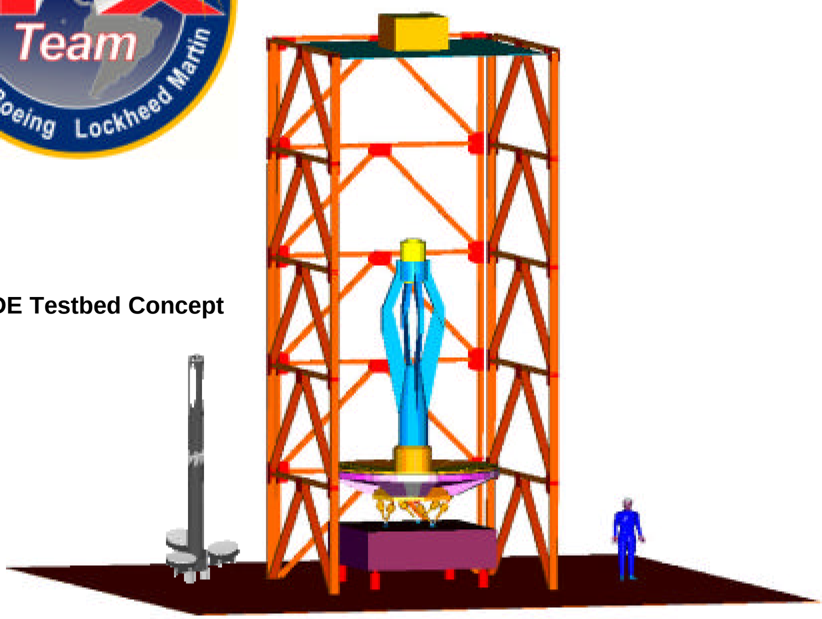
- **Reliable, Stable Deployment Mechanisms**

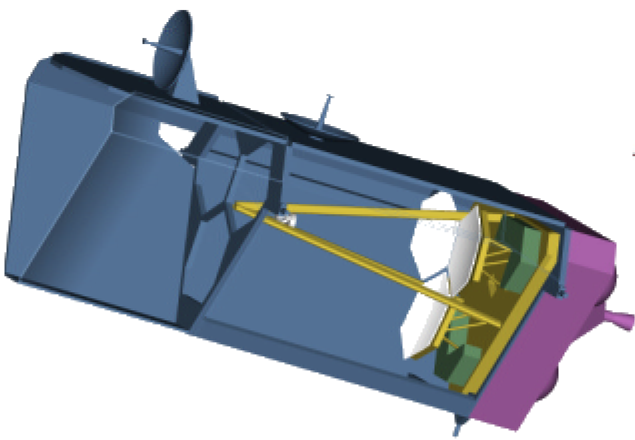
- **Damping Treatments for High Stiffness Structures**
  - Exploit nonlinear characteristics of smart materials for passive damping and isolation

Space-Based Laser

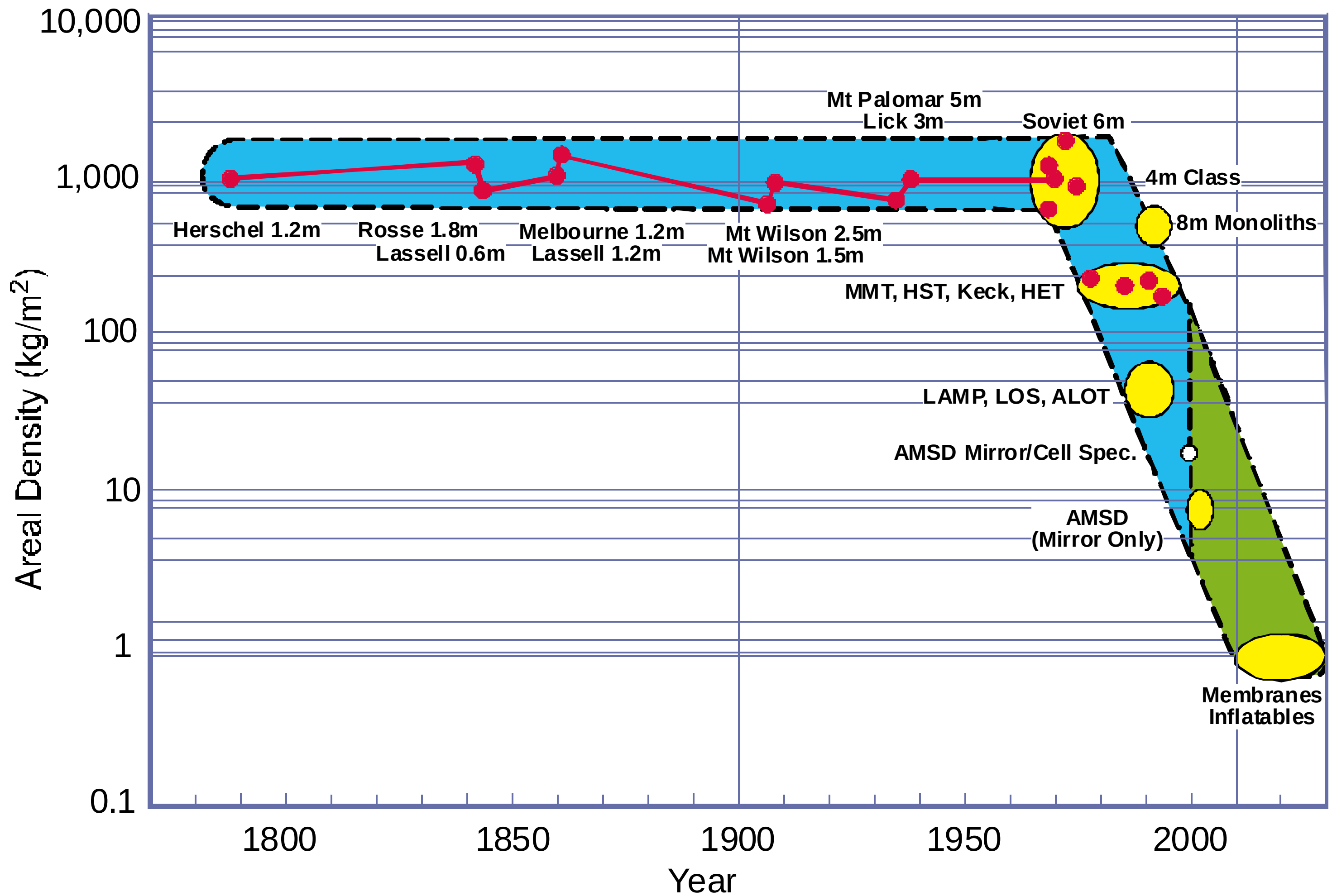
- SBL Beam Director Element
  - AFRL SPICE facility currently baselined
  - SBL structural risk reduction testbed
- NEXUS
  - NASA Deployable Optics Flight Experiment
  - Anticipated launch in late 2004
  - 3-meter segmented telescope design
  - NGST- scale deployment mechanisms

BDE Testbed Concept



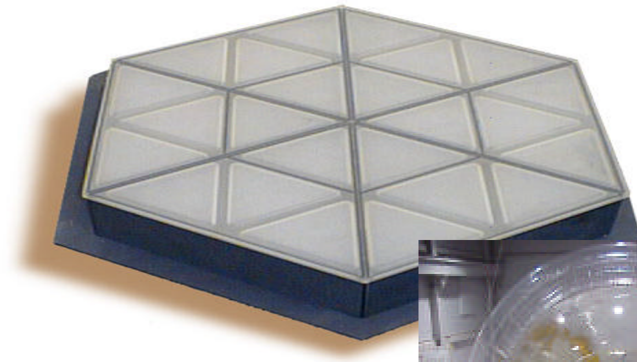


AMSD is an Integral Component of Large Optics Revolution



Approximate Area Density of Large Mirrors 1789-2030

Advanced Lightweight Mirrors



Motivation:

Mirrors are principle driver of mass and volume for large optical space systems. Economical, reliable methods of producir large numbers of lightweight (15kg/m^2) not exist.

ACTUATORS NOW DRIVING MIRROR SYSTEM MASS!!

Technical Objectives:

Areal Density	< 15 kg/m
Shape	Hexagonal
Petal Size	Between 1.2 and 1.5m
Operating Temp.:	
Ambient	300 +/- 10 K
Cryo	35 +20 /- 5 K

Future: Membrane Optics

Areal Density	~1 kg/m

Precision Deployed Structures

Technical Objectives

- Development of precision deployment concepts
  - High stiffness-mechanisms
  - Deterministic load-bearing deployment
  - Sub-wavelength passive stability

Program Description

- Contract (SBIR) Efforts
  - Starsys Phase-I
    - Zero-force precision latch (E-K interest)
  - Foster-Miller Phase-II
    - Integral Hinge Mechanisms (E-K interest)
  - Foster-Miller Phase-I
    - Precision latch
- Collaborative Research
  - NASA LaRC - low-hysteresis hinges
- In-house mechanism testing in PDOS facility

Foster-Miller

STARSYS RESEARCH

SDCL

Vibration Isolation and Suppression System (VISS) Successfully Launched

Technical Objectives

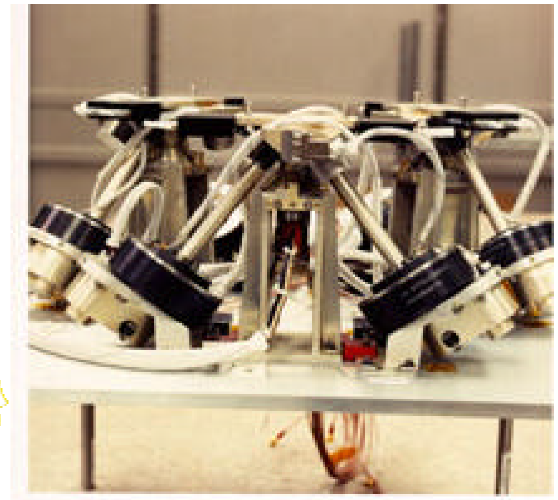
- Demonstrate stable precision sensor platform
- Demonstrate suppression of tonal disturbances
- Demonstrate steering for imaging applications

Program Description

- BMDO sponsored hardware development effort
- AFRL and JPL: software, controller design, performance and qualification testing
- Integrated with STRV-2 Experiment Module on TSX-5 satellite

Hardware Description

- Six hybrid actuators
  - Passive isolation using D-Strut ™ elements
  - Active isolation, steering, and vibration suppression using magnetic voice coils
- Stewart Platform configuration
- Re-programmable flight electronics
- Supports DERA (MOD) MWIR imager



Honeywel
l

TRISYS

JPL

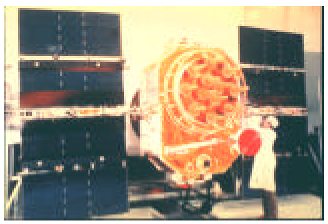
Status

- TSX-5 launch date 07 June 2000
- VISS turn-on ~20 June 2000
- VISS Engineering model delivered to AFRL 31 May 2000
- VISS Mission Ops team ready

NEXT STEP: Need to Miniaturize!!

Technology Challenge: High Power Space Systems

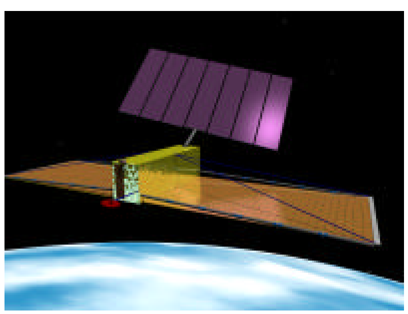
- **Many Current Systems Are Power Constrained:**
  - **GPS IIF uses less power than a common hairdryer**



GPS Satellite
1000 Watts

Hairdryer
1200 Watts

- *Significant Increase in Power Required for Future Systems*

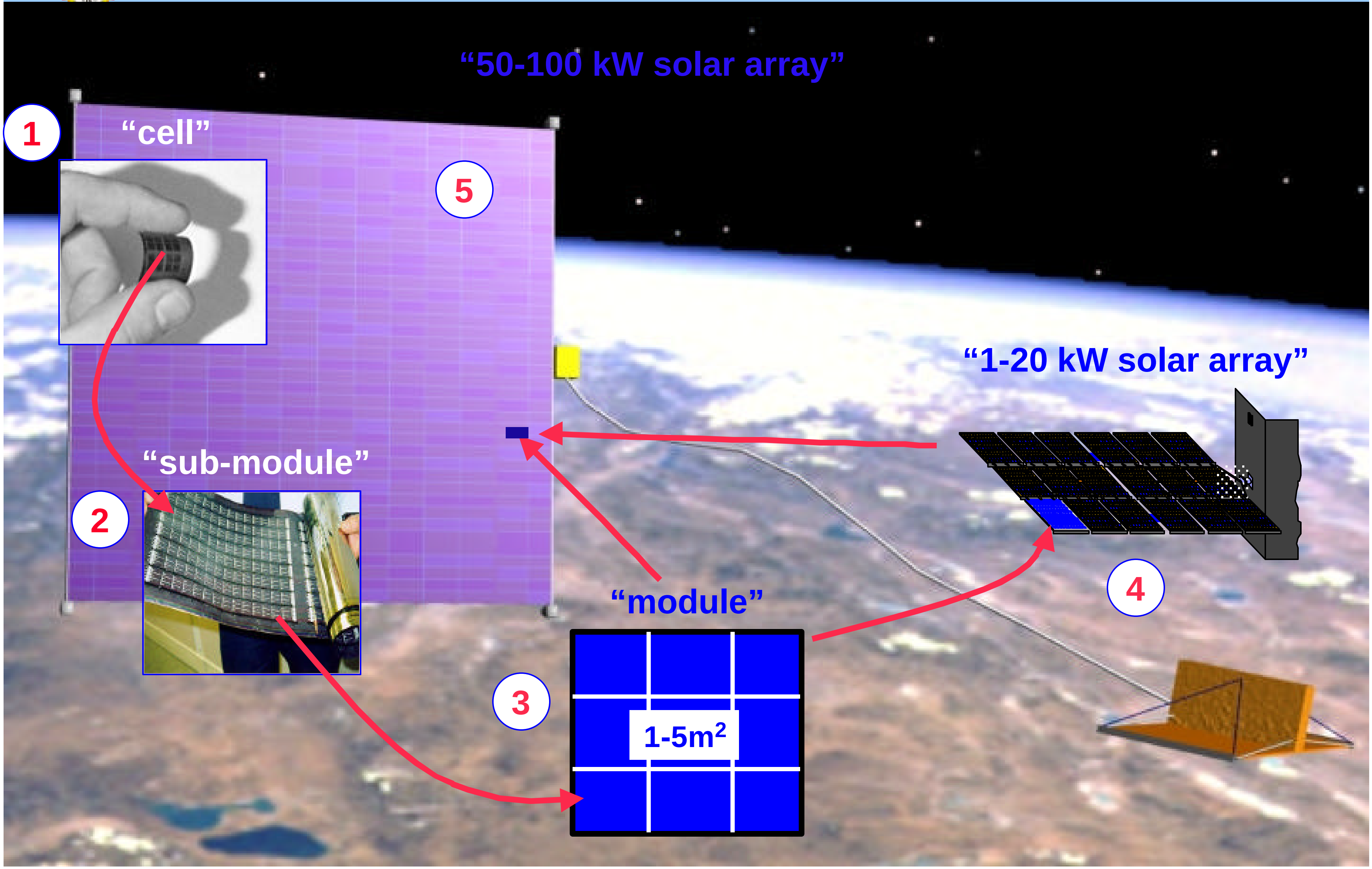


Space Based Radar - Space Based Laser

25kW – 100 kW

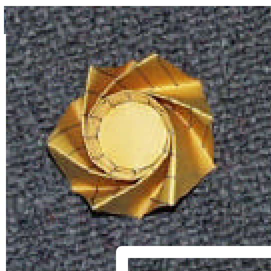
Eliminate Power From The Space Equation

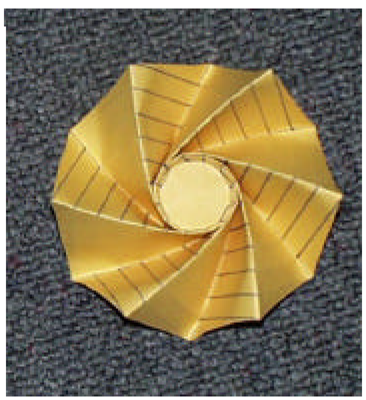
AFRL Power Sail Program

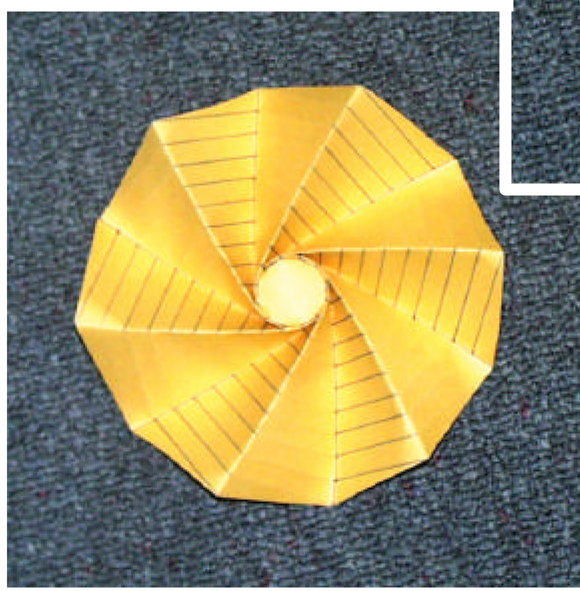


Deployment Sequence: Origami in Space??

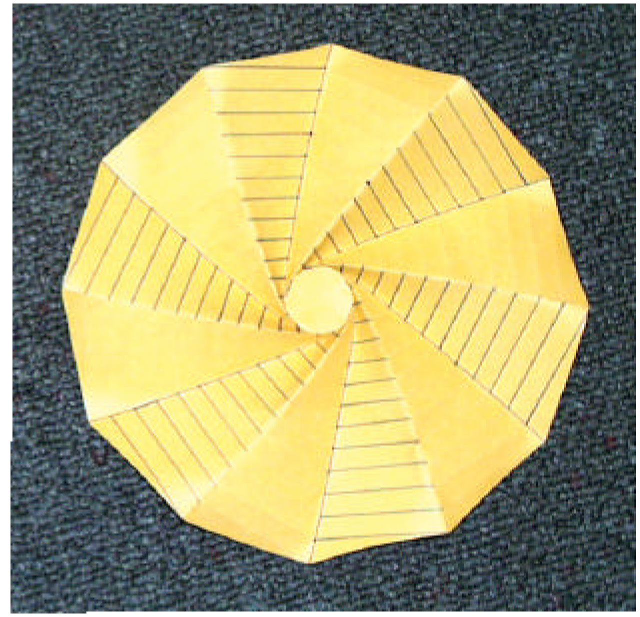
stowed







deployed state



plan view

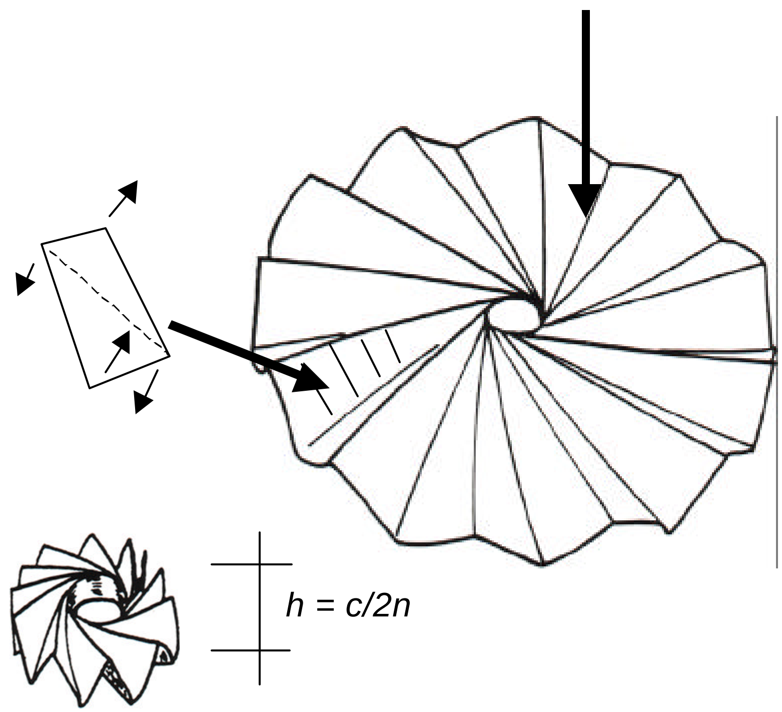
model folded from medium quality paper

Features of Stowage and Deployment

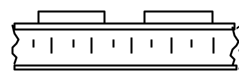
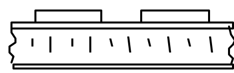
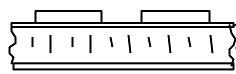
- The panels bend/twist but do not shear during deployment

- The panel sizes vary greatly
- The stowed package is long if n is not sufficiently large

Elastic spars along the spiral folds



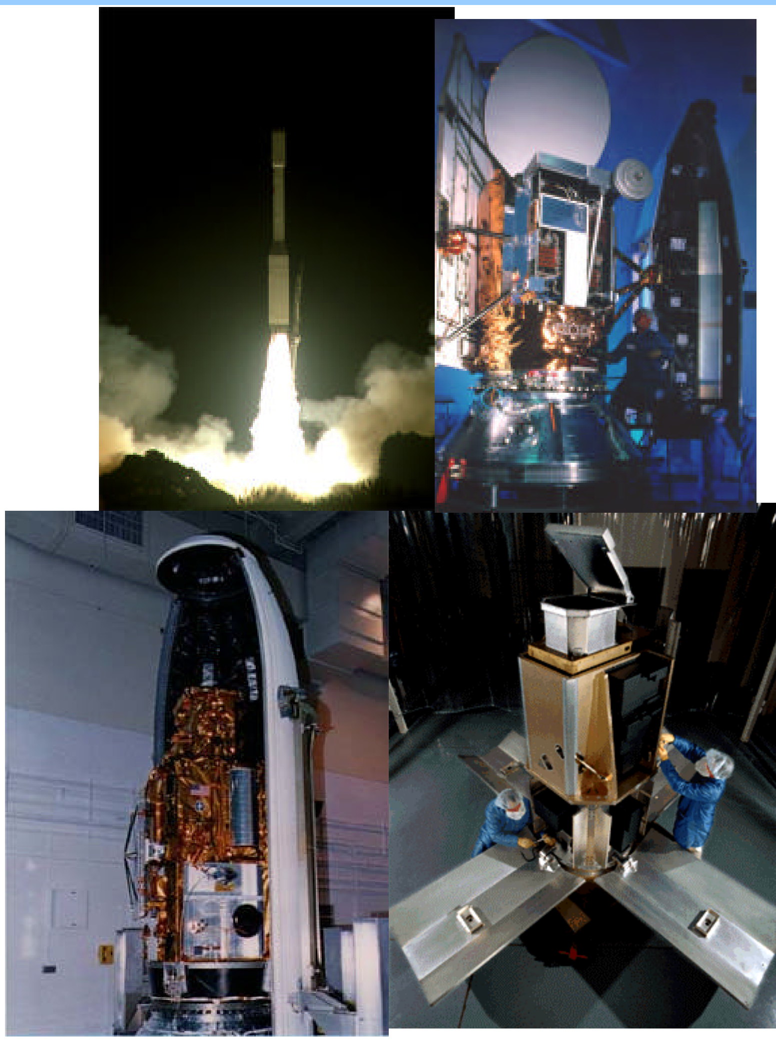
Comparison of Solar Cell Technologies

Array Type	AM0 BOL Efficiency	Panel Configuration	Operating Temp (deg C)	Temp. Factor	Radiation Factor	EOL Specific Power (W/kg)
State of practice, 5.5 mil GaAs/Ge on rigid substrate	18.5%	 Gr/Ep Al H/C Gr/Ep	60	0.93	0.82	36
3-Junction on rigid substrate	**24.0%** **24.0% w/ 1.7X conc.**	 Gr/Ep Al H/C Gr/Ep	60	0.93	0.82	**47** **80**
4-Junction on rigid substrate	**35.0% w/1.7X conc.**	 Gr/Ep Al H/C Gr/Ep	60	0.93	0.82	**116**
FTFPV (CIGS or a-Si) on polyimide*	**10%** **15%** **20%**	**5 mm CIS or a-Si** **1.5 mil polyimide substrate**	75	0.76	0.97	**350** **525** **700**
FTFPV (CIGS or a-Si) on stainless steel*	**10%** **15%** **20%**	**5 mm CIS or a-Si** **1 mil stainless steel**	75	0.76	0.97	**255** **380** **510**
Holy-Grail!! III-V-based thin-film on flex structure*	**35%**	**5 mm III-V MJ** **1.5 mil polyimide**	60	0.93	0.85-0.95	**1225**

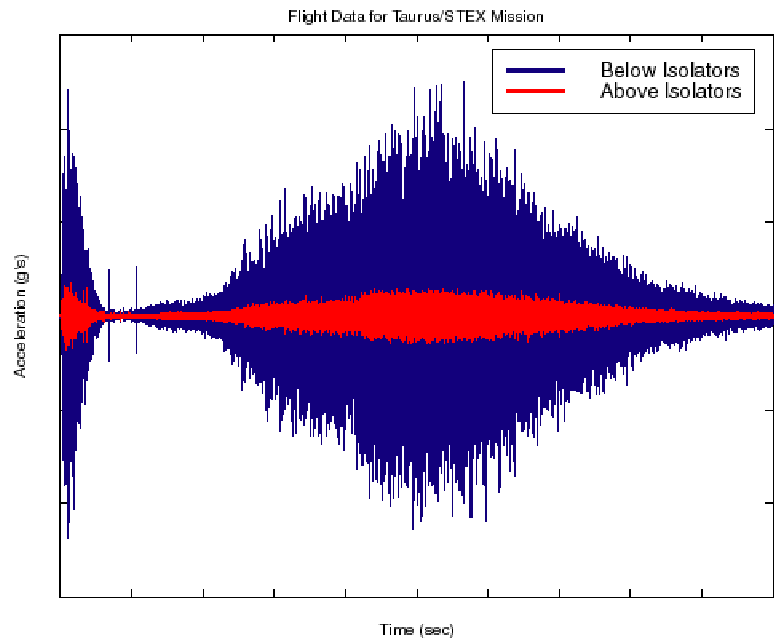
*** Array support structure is 0.1kg/m^2**

FTFPV blanket, interconnects, cabling and thermal control included

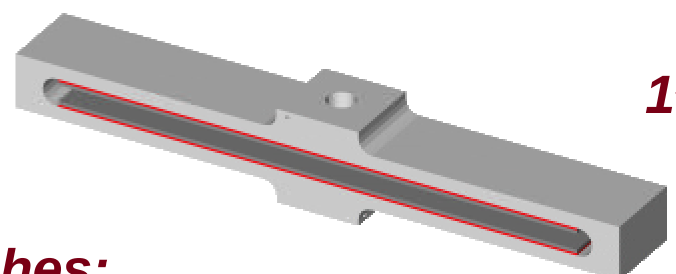
Taming the Launch Environment:
New Success in Launch Isolation



Three Successful Taurus Launches: GFO, STEX, MTI



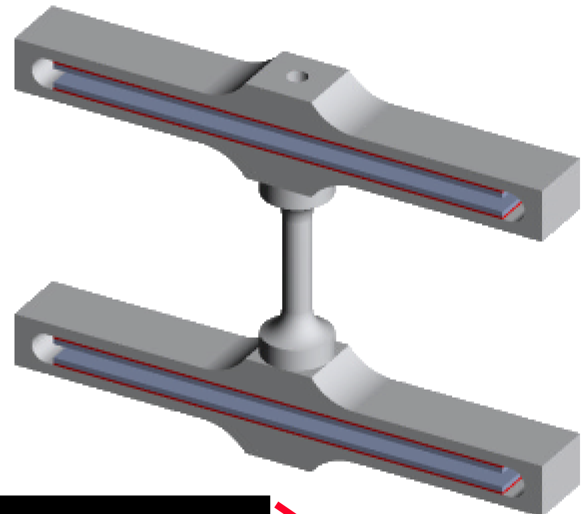
Stex Flight Data

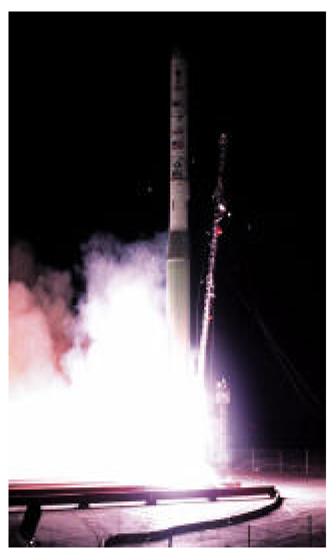


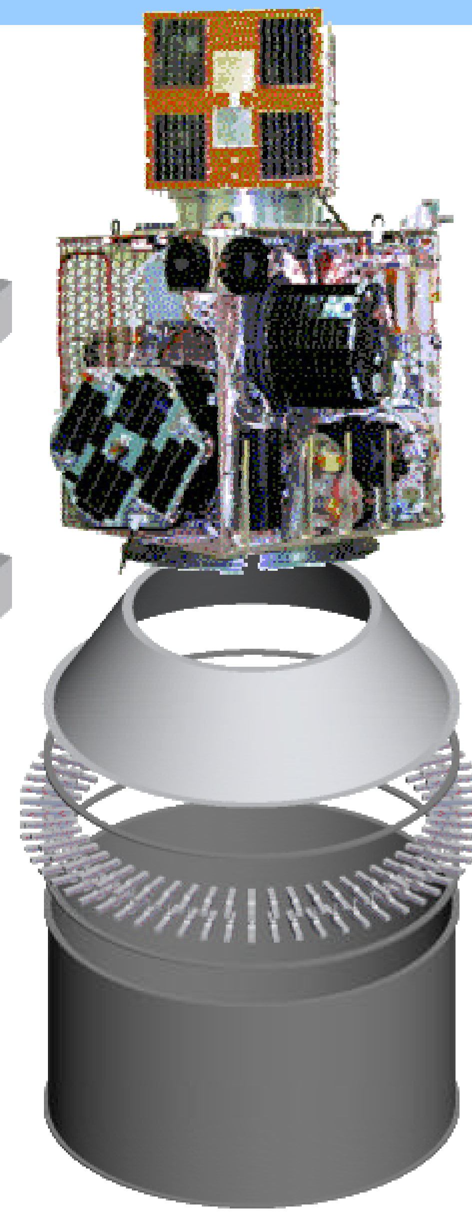
1st Generation Axial Only

OSP/JAWSAT SPECIFICS

- ***Isolation System Properties***
  - **Mass : 25.61 lbs**
  - **Height : 3.5”**
  - **Additional 0.5” and 4.1 lbs Added for This Mission**
- ***Flight Data Concurs with Coupled-Loads Analysis***
- ***JAWSAT Satellite consisted of Five Small Satellites***
  - ***FALCONSAT - Air Force Academy***
  - ***JAWSAT Frame - OSSS and NASA***
  - ***OSCE - AFRL/DE***
  - ***OPAL - Stanford***
  - ***ASUSAT - Arizona State***

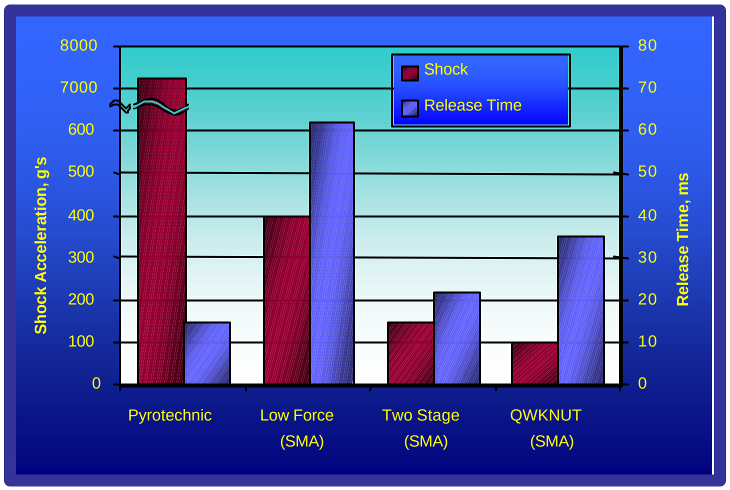


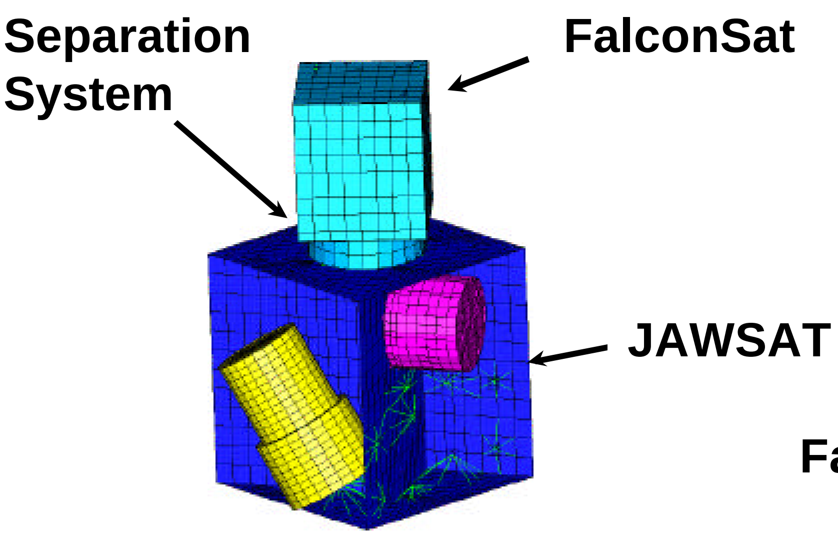


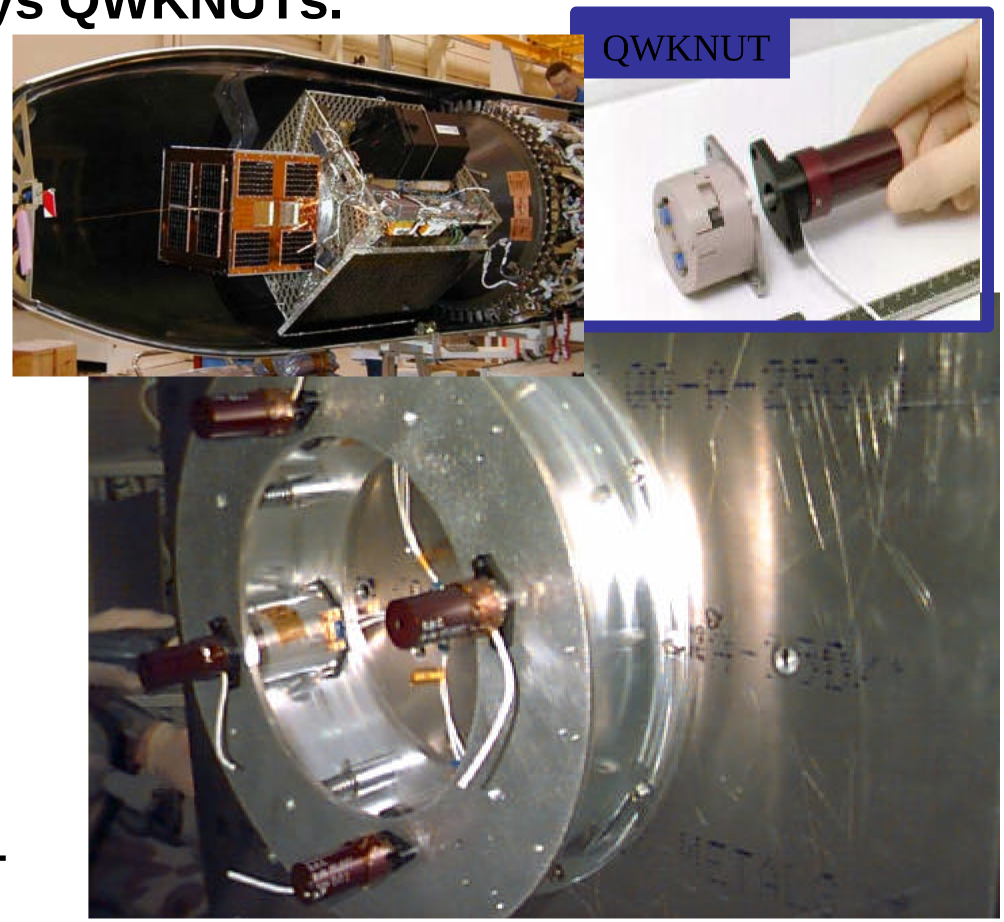


Taming the Launch Environment:
Low Shock Release of FalconSat on OSP-1

- **Air Force Academy FalconSat was successfully deployed from OSP-1 on 27 Jan 00 using four Starsys QWKNUTs.**





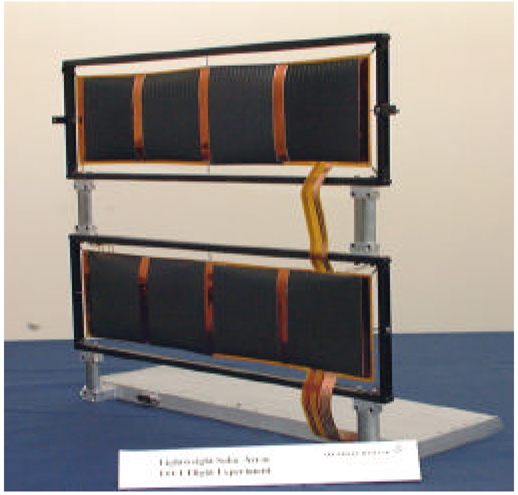


FalconSat Separation System on the test stand

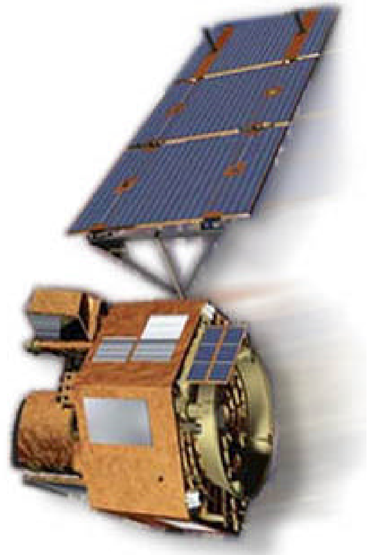
Lightweight Flexible Solar Array (LFSA)
Integrated Subsystem Demonstration

LFSA Benefits

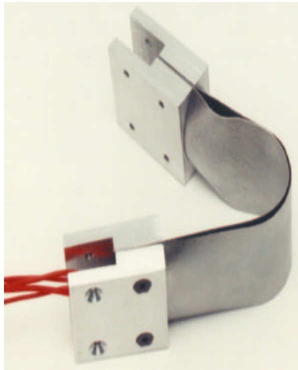
- Demonstrate Specific power >100Watts/kg compared to 40Watts/kg
- Uses CuInSe2 (CIS) 8.6% thin film solar cells on flex Poly
- SMA hinge and deployment systems for controlled deployment
- Low stowage volume
- MFS - PV substrates with integral traces leading to 30% mass cut in cable harness



LFSA Demonstration Panel



EO-1 Spacecraft
Summer '00

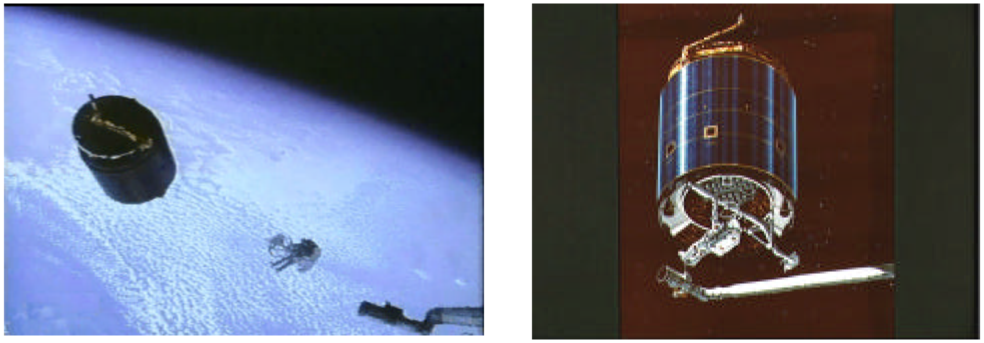


Shape Memory Alloy Hinge Successfully Demonstrated on Shuttle

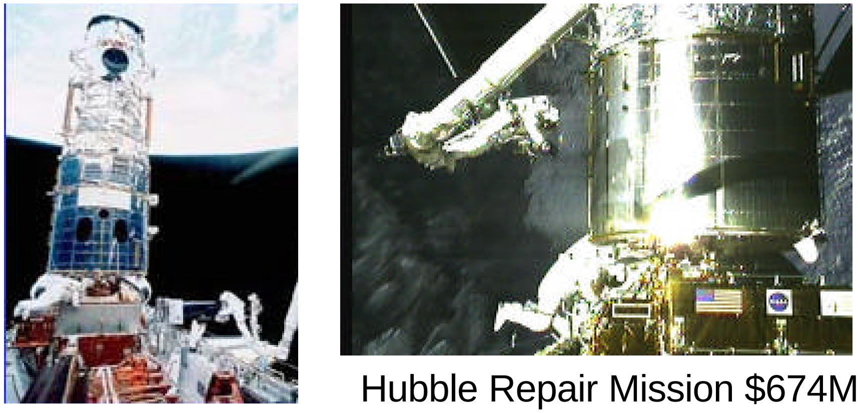
Historical Challenges of Space Servicing

<u>Impediments to Current Space Servicing</u>

- **Costs more to service than to replace**
- **Takes too long**
- **Limited repairability of satellites**



IntelSat VI Rescue Mission $96M (Hughes) + $450M (NASA)

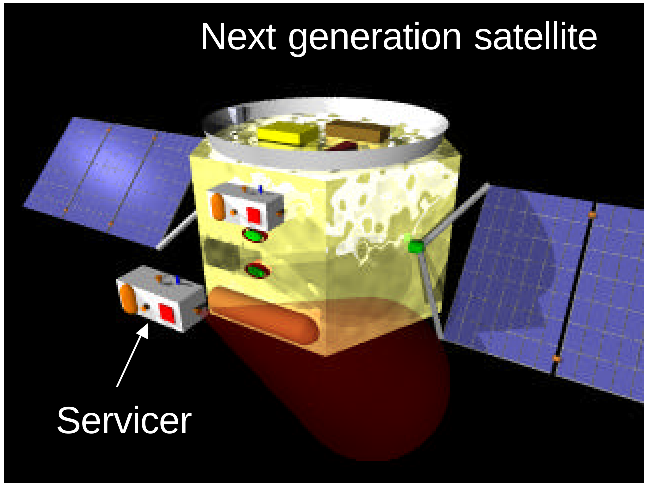


Hubble Repair Mission $674M

Inexpensive, Simple Autonomous Operations, and Fast Response Servicers Are Required to Make Space Servicing Routine

Elements Required for Inspection and Servicing of Space Assets

- **Satellite designed for on-orbit servicing**
  - **Open architecture backbone**
    - **e.g., PC-like bus**
  - **Ports available from outside**



- Autonomous, low cost, vision-guided inspector/servicer
  - Finds, inspects, docks and services
  - Provides satellite visual assessments, replaces modular components, and replenishes expendables

Revolutionary paradigm shift in satellite design and operations

Conclusion

- **Time is Ripe for the Insertion of Smart Structures and Materials into Space Systems**
  - Recent Space Demonstrations
  - More Stringent Requirements
- **Military Systems**
  - Low Cost
  - Large Aperture
  - Launch Costs
- **AFRL Focus**
  - Rapid Transition through Demonstration
  - Requires Inter-Government as Well as Industry Cooperation ($$)